Title:

Integrated Weed Control in Transplanted Pepper: Evaluating the Use of Between-Row Cultivation Tools with Banded In-row Applications of 200-grain Vinegar

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Abstract:

Vinegar, an organic herbicide, can supplement the existing intra-row weed control options of organic farmers. However, there are two primary limitations to its use in vegetable crops. First, it is expensive. Second, vinegar applications that contact the crop can cause injury and yield loss. The aim of this research was to use vinegar to control intra-row weeds in bell pepper in a way that product costs would be reduced and crop injury would be minimized. Vinegar was banded in-row to reduce product volume and expense. Applications were shielded and directed below the crop canopy to minimize contact with crop foliage. Stem protectants, organic paints applied to crop stems, were included and evaluated as potential physical barriers to crop stem injury. A tractor mounted sprayer/cultivator was constructed to apply a 25 cm-wide band of vinegar at the base of two crop rows, while the inter-row areas were simultaneously cultivated. Two trials were conducted in transplanted bell pepper. A single application of 200-grain vinegar (20% acetic acid) at 700 L/ha was applied when weeds were in the cotyledon to six-leaf stage. Applications were made with the lower stems coated in one of two organic paints (linseed oil and clay-based) or left uncoated. Handweeded and weedy in-row treatments were included for comparison. One day after vinegar application, in-row weed control was 100% in both pepper trials. Two weeks after application, there were 75% fewer weeds germinating in the vinegar treated areas, as compared to the areas which were handweeded. With vinegar, there was minimal soil disturbance, so the potential to stimulate latent weed seed germination was significantly reduced. Neither stem paint prevented crop injury; the clay paint flaked off within 2 weeks while the linseed oil was phytotoxic. Despite pepper foliar injury of less than 5%, stem injury by 2 weeks post-application contributed to a measurable reduction in yield. With vinegar, high levels of weed control, and the extended duration of that control relative to handweeding, could facilitate improved organic intra-row weed control. However, crop injury must be reliably reduced beyond the levels found in these studies. More research will be needed to assess the value of alternative stem protectant materials.

Background and Justification:

Managing weeds in pepper can be a challenge. Pepper is a poor competitor with weeds; left unchecked, yields are dramatically reduced. Hand-harvesting of pepper is also slowed in weedy fields, further increasing costs. Pepper production, particularly organic pepper production, requires new reliable and highly effective weed management strategies.

Each year, conventional pepper farmers spend from 200 to 450 $/acre on weed management (Klonsky et al. 1997; VanSickle et al. 2007). Organic pepper growers have even higher weed management costs since a greater portion of the weeds are controlled by handweeding. Cultivation and handweeding of the row middles between pepper grown on plastic can cost 800 $/acre (Anonymous 2006).

Current weed management options are limited. There are few herbicides for conventional growers and none for organic growers. As such, there is often a need for rigorous handweeding. The current extensive use of black plastic to suppress weeds is both costly and a source of environmental contamination. Cultivation has been used with success for inter-row weed control. However, close cultivations can injury the shallow roots of pepper plants, and in the case of plastic-culture, cultivations to the sides of plastic run a high risk of lifting or tearing the plastic.

In 2007, peppers in the U.S. were grown on more than 90,000 acres (bell and hot pepper combined), with two-thirds harvested for fresh-market. Leading production states include California, Florida, New Mexico, Texas, and New Jersey (USDA Census of Agriculture 2007). Over 20 states have at least 200 acres of peppers in production. In 2008, U.S. production of organic bell pepper was valued at over 8 million dollars with an annual production of over 120,000 tons (USDA Organic Survey 2008). Thus, there are sizable acreages of pepper, all across the United States, which could be influenced by this research.

The objective of this project was to evaluate the use of 200-grain vinegar as a direct substitute for intra-row handweeding, while using previously developed cultivation tools to effectively manage between-row weeds. The between-row cultivation and in-row vinegar application can occur in a single tractor operation with our constructed tool (Figure 1). Coupling the use of vinegar to control in-row weeds with the use of between-row cultivation tools would substantially decrease the amount of product needed per acre (a 2/3rd reduction with a 10-in wide banded application to crop rows spaced 30-in apart).

Figure 1. A Cultivation/Sprayer toolbar that allows for simultaneous cultivation of between-row weeds while directing a shielded 10-inch wide band of a natural product in-row.

Objectives

1) *Evaluate the in-row weed control potential of 200-grain vinegar.*
2) *Evaluate crop response to applications of 200-grain vinegar, with and without the use of organic stem protection.*
3) *Evaluate the cost of each treatment.*
4) *Project evaluation.*

Procedures

Field trials were conducted in the summer of 2009 at the H. C. Thompson Vegetable Research Farm in Freeville, NY. Trials in transplanted bell pepper 'Lady Bell' were repeated in two different fields. Soil in all fields was a Howard gravel loam (HGL; loamy-skeletal mixed mesic Glossoboric Hapludalf). All fields were moldboard plowed, disked, fertilized, and field cultivated prior to transplanting.

Two days before transplanting, the bottom 12 cm of pepper stems were coated in one of two organic paints, a linseed oil[1] or a clay based product[2], or left uncoated. Paints were manually applied with a small bristle brush. Plants were then mechanically transplanted 60 cm apart, in rows spaced 76 cm apart. Each plot was 1.5 m-wide and contained two, 7.6 m-long crop rows. Trials were randomized complete block designs with four replications.

A single application of 200-grain vinegar, at 700 L ha^{-1}, was applied to plants with each stem protectant, and to those without. The 25 cm band of vinegar was centered at the base of each crop row, and directed beneath the crop canopy. Applications were made at a 2 km hr^{-1} travel speed. Additional treatments were included where stem paints were applied to pepper, and the in-row area kept weed free with handweeding and hand hoeing. These treatments were to assess potential paint phytotoxicity. Handweeded and weedy in-row treatments, both without stem paint, were also included for comparison. Cultivation tools were used to control weeds in the inter-row area of all treatments.

Peppers were planted on June 1st, cultivated and sprayed 14 DAP, when pepper was at the 8 leaf stage (20 cm tall), and then cultivated again 38 and 46 DAP. Peppers were harvested at 65, 72, and 82 DAP. Targeted weeds were in the cotyledon to six-leaf stage and included (in order of prevalence) hairy galinsoga (*Galinsoga quadriradiata Cav.*), common lambsquarters, redroot pigweed (*Amaranthus retroflexus* L.), large crabgrass (*Digitaria sanguinalis* L. Scop.), and shepherd's-purse.

Permanent 0.25 m^2 quadrats were established in the center of each crop row in each plot (two per plot) one day after vinegar had been applied. The number of surviving weeds were counted in each quadrat. These weeds were then cut at their base and discarded. Quadrats were revisited two weeks later and counts were taken of emerged weeds. In-row weed counts in the handweeded-only treatments were done in an identical manner at one day and two weeks after the first handweeding. The initial handweeding in the handweeded treatments occurred on the same day as the vinegar application. Crop injury and yield data were collected for all treatments. With exception of the weedy check, all treatments were kept weed-free until harvest. Handweeding events were timed in each treatment.

All data were subjected to ANOVA. The PROC MIXED procedure in SAS statistical software[3] was used to assess the main effects of stem treatment, crop type, and the presence or absence of vinegar, for their influence on yield relative to the handweeded control. Fisher's protected LSD tests were conducted to compare selected treatments, with significance values set at $P \leq 0.05$.

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[1] Allback Organic Linseed Oil Paint, Viking Sales Inc., 7710 Victor-Mendon Rd., Victor NY 14564

[2] Green Planet Paints: Interior Eggshell Sorrel, Green Planet Paints, 9413 N. Central Ave., Phoenix AZ 85020

[3] SAS 9.2. SAS Institute Inc, 100 SAS Campus Drive, Cary NC 27513

Project Evaluation

Project success is measured by the potential for these weed control methods to be put into practice by members of the organic community. Results that show minimal crop injury or yield reduction with the use of in-row directed applications of vinegar will provide strong supporting evidence for the adoption of this new IPM tactic for managing in-row weeds within a host of transplanted crops (i.e.: pepper, broccoli, basil, tomato, eggplant). Project demonstrations and presentation of results at grower meetings will facilitate outreach and adoption.

Results and Discussion

Weed Control

Vinegar provided a high level of weed control one day after application (Table 1). Control in the vinegar treatment did not significantly differ from that in the handweeded treatment. There was 100% weed control in both pepper trials. Weeds were in the cotyledon to six-leaf stage at the time of application. Research has shown that targeting weeds at these smaller sizes will maximize control (Abouziena et al. 2009; Evans and Bellinder 2009; Evans et al. 2009).

Table 1. Weed survival in pepper trials one day after in-row handweeding or vinegar application[a].

Treatment	**Pepper** Trial I	**Pepper** Trial II	**Mean of Trials**
	Number of weeds per 0.25 m^2 1 day post-treatment		
Weedy	10 a	34 a	22 a
Handweeded	0 b	0 b	0 b
Vinegar 700 L/ha	0 b	0 b	0 b

[a] Within each column, means followed by different letters were significantly different (P≤0.05, LSD).

The duration of control is important. Since vinegar does not have residual activity, control will not persist over the long-term. In this study, vinegar reduced post application weed germination relative to in-row treatments which were handweeded and hand-hoed (Figure 2). Because vinegar applications did not disturb the soil, fewer weed seeds were exposed to light or otherwise stimulated to germinate. Thus, the duration of in-row weed suppression will be longer when vinegar is used rather than cultivation or handweeding

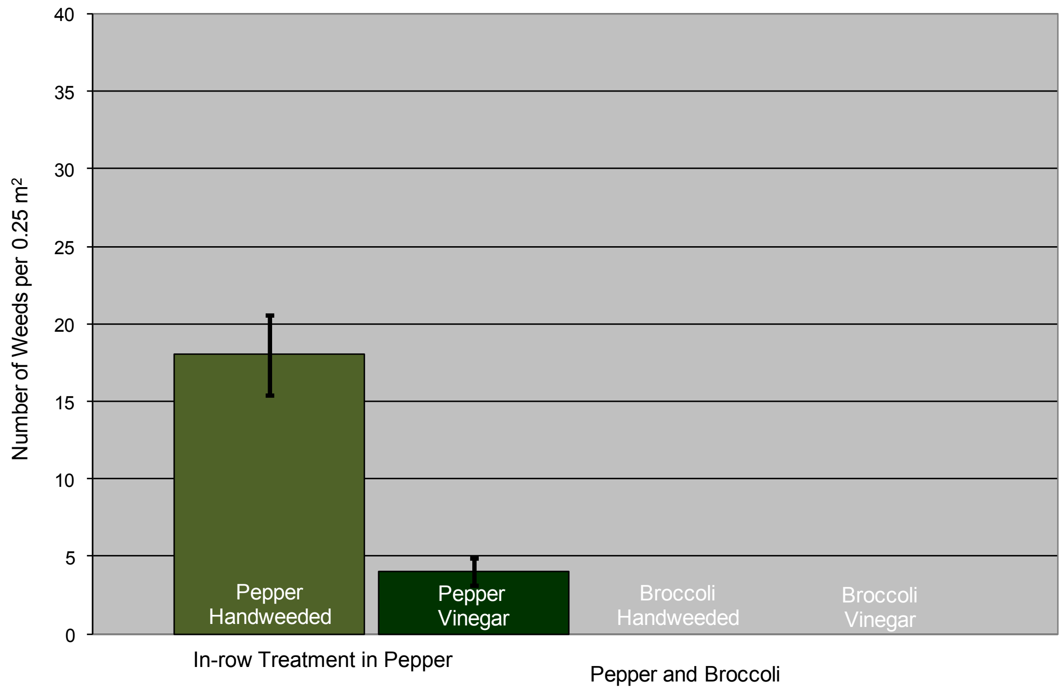

Figure 2. In-row weed counts in pepper 2 weeks after vinegar applications or handweeding had occurred (data combined across trials). Standard error bars are shown.

The directed band applications of vinegar reduced the need for supplemental handweeding. Time spent handweeding, extrapolated to hours/ha, is shown in Table 2. In these trials, handweeding a hectare of pepper required an average of 167 hours of labor. Lanini and Le Strange (1994) found that season-long weed control of a hectare of pepper required 200 or more hours of handweeding. Similarly, Gianessi and Reigner (2007) reported that handweeding a hectare of hot pepper took 149 hours. Relative to the handweeded-only treatments, the vinegar treatments provided identical weed control with a 70% reduction in time spent weeding (averaged across both trials).

Treatment differences in handweeding times translated into differences in weed management costs. If handweeding costs are averaged at $7/hr, then the integration of vinegar for in-row weed control would reduce handweeding expenses from over $1000/ha to around $175/ha. The in-row vinegar application would cost an additional 145 to 580 $/ha, depending on the source of product. There is also the purchase cost of the sprayer to consider. The sprayer used in these trials was built for around $400. There may be a cost-justification to in-row applications of vinegar, with the important stipulation that crop yield is not reduced.

Table 2. The duration of intra-row handweeding in the handweeded and vinegar treatments of each pepper trial[a].

Treatment	Pepper Trial I	Pepper Trial II	Mean of all Trials
	Time of intra-row handweeding (hr/ha)		
Handweeded	175 a	158 a	167 a
Vinegar 700 L/ha	50 b	50 b	50 b

[a] Within each column, means followed by different letters were significantly different ($P \leq 0.05$, LSD).

Crop Response

Crop response to vinegar, without stem protection, was dependent on two factors: the successful integration of the spray system to accurately direct the spray below the crop canopy; and, the inherent resistance of the crop to injury. With pepper, initial post-application tolerance to vinegar was excellent, with less than 5% injury one day after treatment (DAT; data not shown). However, scarring of the stems contributed to a delayed injury response; by two weeks after treatment a significant portion of the treated pepper plants had fallen over or broken off at their base (Figure 3). These responses were due to a physical weakening of the lower plant stems (Figure 3).

Yields of pepper were reduced with vinegar applications, regardless of whether stem paints were included (Figures 4). Within a main effects multivariable model, crop type, stem treatment, and the presence or absence of vinegar all significantly influenced ($P \leq 0.03$) the level at which yields were reduced relative to the handweeded control. The negative yield response was due to crop injury, and not weed competition. Pepper yields were measurably reduced with vinegar applications (Figure 4). Stem injuries contributed to over a 50% reduction in per plot yields (Figure 4). Per-plant yields, and the total number of harvestable peppers, were likewise reduced (data not shown). Feasible integration of vinegar in pepper will require protection or shielding of the stem.

Yield reductions with vinegar were not significantly different than those found in the weedy checks; thus, there was no yield advantage to including vinegar (Figure 4). Coffman et al. (2004) found less than 5% injury of sweet corn and soybean when 200-grain vinegar was applied at their base to the point of runoff. It is possible that other crops may have more innate tolerance to basal vinegar applications. Decreasing the vinegar application volume and/or concentration may lessen crop injury, although weed control might also be reduced.

Figure 3. Application of 200-grain vinegar (700 L/ha) on pepper. Top: plot photos were taken 2 (left) and 14 (right) days after application. Many plants had fallen over by 14 days after application. Bottom: lower stem injury due to contact with the vinegar (note flaking of the clay-based stem paint).

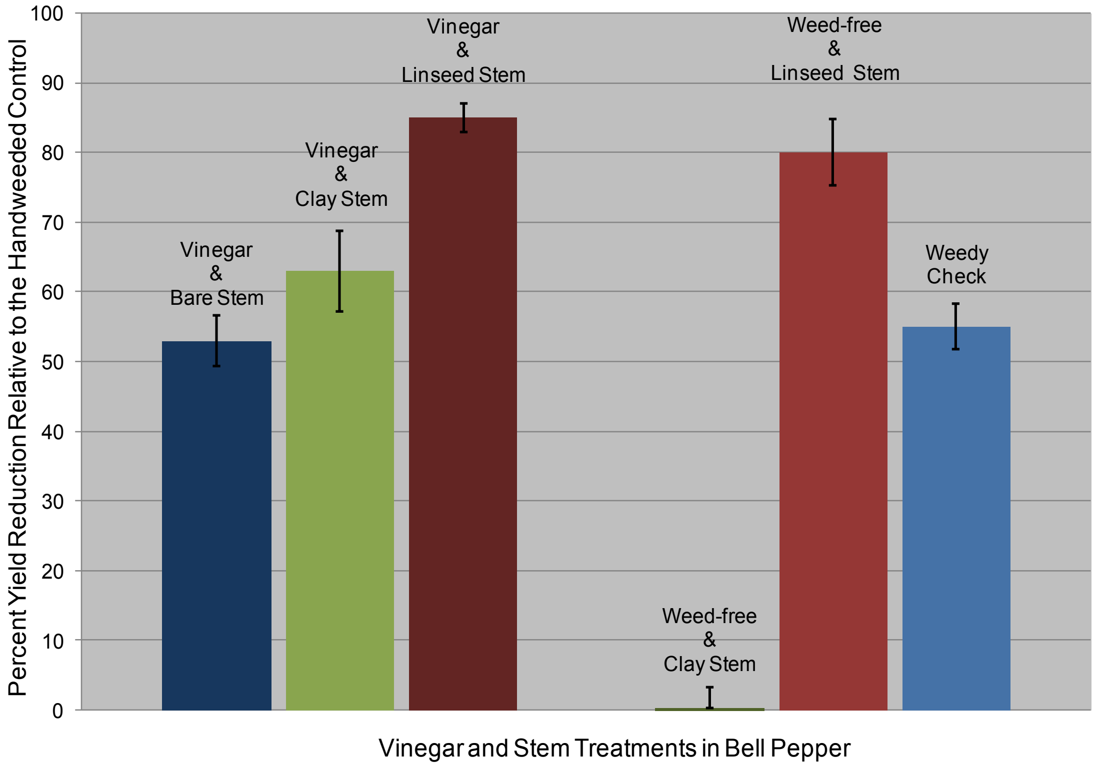

Figure 4. The percent yield reduction of bell pepper, relative to the handweeded control, in treatments where vinegar was applied with and without a stem protectant, and where stem protectants were applied alone. Data was combined across trials. Standard error bars are shown.

Stem Protectants

Both stem protectants failed to prevent crop injury. The clay paint flaked off by the time of application (2 weeks after painting). Therefore, stem injury was not prevented. The addition of the clay paint alone, without vinegar, did not impact crop yield (Figure 4). The linseed oil protectant formed a longer lasting stem coating; however, the paint was phytotoxic to pepper. This resulted in significant yield loss when the linseed oil was applied without vinegar, and amplified yield loss when it was applied with vinegar (Figure 4). Neither of the tested organic paints show promise as stem protectants.

Future work will evaluate directed sprays of vinegar along with alternate stem protectants, in the hopes of providing a longer-term physical barrier without phytotoxic effects. One possible organic barrier is the stem of Japanese knotweed (*Polygonum cuspidatum*). These stems are hollow, and short sections could be slipped around the lower stems of transplants, including pepper, much like trunk guards are used on fruit trees. The protectors would naturally decompose and would not require removal from the field. By coupling a viable stem protectant with the application strategies used in this research, crop safety of sensitive crops may be achievable. If successful, such techniques could facilitate the use of additional organic and conventional contact (e.g.

paraquat in pepper) or foliar/stem absorbed herbicides in crops, which if treated otherwise, would be injured.

The cost of purchasing and applying a stem protectant needs to be considered. In this research, hand painting of crop stems would take 30 hours/ha, considering the crop spacing that was used in these trials. The cost of the paints was between 40 and 65 $/ha. An automated application of such paints would measurably decrease labor time and expense. Alternative stem protectants, like the Japanese knotweed stem sections, could be acquired with limited expense (time to harvest, cut and install stem sections wound need to be considered) and would have no product labeling concerns. Compared to the cost of handweeding, the expenses of a stem protectant and a vinegar application may be justifiable. But, for this integrated system to be financially viable, crop stem and foliar injury must be reduced below the point at which yields are impacted.

Vinegar may have potential for in-row weed control. High levels of initial control, and the duration of that control, indicate that there is merit to using vinegar in-row relative to handweeding or hoeing. However, for vinegar to be feasibly integrated in vegetable cropping systems, crop injury must be reliably reduced beyond the levels found in these studies. Using a directed sprayer, like the one trialed, will lessen foliar injury. Nevertheless, stem injury remains a critical concern, particularly with sensitive crops like pepper. Stem protectant materials may aid in physically shielding crop stems, but more research on alternate products will be needed.

Project Locations

Research was conducted at the Homer Thompson Research Farm, in Freeville NY (Tompkins County).

Project findings are applicable nation-wide.

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Additional Photographs of Novel Sprayer/Cultivator

Images of the banded directed sprayer. Clockwise from the top: side view of sprayer (black) mounted to the rear of an inter-row cultivator (blue) with pivot points (A) and height-adjustable wheels (B); side view of sprayer raised in transport position with CO_2 pressure tank and vinegar holding tank (C); close-up of spray shield shape and orientation.